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GOING BEYOND THE FARM BOUNDARY

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Small-scale farming diversity and bioeconomic environment variability: A modelling approach SUB THEME : 1.2. Integration of micro-strategies with macro-economic factors

Abstract

Modelling is seen by many scientists as a powerful tool to assess the interaction between variability in the bioeconomic environment of small-scale farmers and their resource management strategies. Two case studies on small-scale farming in Mexican and Brazilian savannas are presented. On one hand, the effect of climate variability on crop yields is highly dependent of the managing techniques used. On the other hand, the variability of prices, resulting in Mexico's case from the establishment of NAFTA and, in the Brazilian case, from the "plano Real," dramatically increases the uncertainty of the economic results linked to technical choices. Modelling the real conditions of such farmer decisions requires integrating of both biophysical and economical knowledge. This work analyses the characteristics required for such models and ways to integrate them. It appears that the building and scaling up of the models should be driven by results of a study on farming system diversity.

Key-words: *risk, modelling, small-scale farming.*

Small-scale farming diversity and bioeconomic environment variability: A modelling approach
Introduction

In two regions of Latin America -- the Silvânia *Municipio*, situated in the state of Goias, Central Brazil, and the San Gabriel zone in Jalisco State, western Mexico -- small-scale farmers have shown constrasting attitudes toward technical innovations proposed by research and extension services. In Mexico, a system of no-tillage sowing into a mulch of maize straw residues has not been adopted by farmers, despite being seen by scientists and extensionists as an efficient way to increase yields and reduce soil erosion where rainfall is scarce. In Central Brazil, a technical package that includes use of improved crop and forage cultivars, fertilizers, soil tillage machinery, and productive cattle stock replaced within a few years a long-lasting traditional system based on manual and animal-tracted tillage. Extension methods in both cases were based largely on similar principles, and were thus not considered as the main influence on farmers' decisions. Our hypothesis is that the differences in decisions to adopt new technology resulted from similar and rational resource management strategies under differing bioeconomic environments. To test this hypothesis, we intend to evaluate *ex-ante* the impact of technical innovation on the farms, according to their diversity and taking into account the bioeconomic environment and its variability in space and time. This paper presents a modelling methodology, describes the first results obtained, and discusses their implications for a modelling approach.

Characterization of the production context in the two regions

Major exogenous factors that affect farming activity include (i) climate, as it determines crop growth, and (ii) input and

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output prices, as they determine production functions and farmers' attitudes to the market. Both vary significantly over time in the regions studied.

Climate variation and crop management

Technical choices such as planting date and density, cultivar phenology and vegetative structure, and soil management affect crop response to climate. Climate-based risk in agriculture, therefore, depends not only on changes in climate over time, but also on the management techniques used by farmers. To explore this combined effect of climate variation and management on yield variability for the study regions, a simple agroclimatic model was designed and validated for maize (Affholder *et al.* 1997; Scopel *et al.* 1998), the central crop for production systems in both regions. The model was applied to long-term weather data and for two sets of management techniques, "traditional" and "innovative," for each region. The innovative practices led to higher average simulated yields in both regions, but with contrasting risk: in Mexico, no-tillage sowing in straw residues (not yet adopted by farmers) would notably reduce yield variability over time, whereas in central Brazil (where innovative practices involving improved varieties, fertilizer, and tillage machinery were broadly adopted by farmers over 1993-95), variability in yield would clearly increase (Table 1).

Economic variability

Both Brazil and Mexico have implemented economic adjustment and liberalization programs leading to price variability for both inputs and outputs. In Brazil, the "Real Plan" started in July 1994 drastically reduced inflation, decreased interest rates, and brought price transparency. Simultaneously, the country has been linking up with and helping establish the emerging regional trade market, Mercosul, and government price supports for agriculture have been progressively suppressed. In Mexico, the agrarian-reform land-tenure classification of the *ejido* was modified, allowing the sale of such land. Moreover, in 1994, under the North American Free Trade Agreement (NAFTA), import tariffs were lowered to an average of 5%. Under NAFTA' s agricultural provisions, all tariffs, quotas, and licenses that restrict agricultural trade between the United States and Mexico will be eliminated by the end of the 15 years implementation period. Agricultural trade between Mexico and the US will be completely liberalized by 2008. At the same time, support to agriculture changed from a policy directed at prices to a one that targets revenues. Under this scheme, farmers receive a fixed amount of cash during each cropping cycle, whether or not they sell their products, but prices are no longer subsidized.

Macro-economic changes in both countries were buffered by favourable maize prices on the world market in 1995-96. However, as of 1996, world prices of maize fell nearly to 1993 levels, whereas input costs increased -- less favourable circumstances for maize farmers.

Evolution of the farming systems

In our two study areas, direct observations of farming systems performed simultaneously during the last five years showed notably differing effects from macro-economic changes. In the San Gabriel zone in Mexico, the effects appear to be slight, while changes in Silvânia were dramatic: a significant number of farm units started a rapid process of intensification and specialization toward dairy production, associated with a slight decrease in the importance of crops in the farm income and the adoption of numerous technical innovations. Others selectively adopted innovations but maintained a high level of diversification in activities. Finally, the production systems of remaining farms were nearly unchanged. In all cases, the innovations adopted included cropping techniques that increased climatic risk, as described above.

Macroeconomic data suggest that in both regions farmers would have to develop anti-risk strategies to face market uncertainties, and the biophysical data suggest that the zero-tillage technology proposed in Mexico could constitute an appropriate element in such strategies, whereas the technical package adopted in Brazil is more risky. These apparently surprising results show that, in evaluating adoption, simple analysis of factors exogenous to the farms, such as climate and prices, is not enough. In fact, the risk associated with new technologies must be analysed at the farm level, as yield variability may not be a problem if the cost of the inputs associated with the technique is always lower than the output value. A precise assessment of such interactions between exogenous and endogenous factors requires modelling.

General methodology

The conceptual framework

To evaluate the impact of technology innovation on farm households, we have developed a conceptual and methodological framework that draws on several scientific references: the rationality concepts, the systems approach, the local approach, and modelling. With regard to the decision process and the rationality of farmer behavior, we have used the bounded rationality concept defined in general terms by Simon (1960) and in specific ones for farmer decision-making by Brossier et al. (1991). It is generally assumed that a farmer makes rational decisions based on knowledge of:

- Available on-farm resources (endogenous factors)
- The biophysical and economic environments (exogenous factors)
- Available management techniques

As his knowledge of the evolving bioeconomic environment is incomplete, he has to face a risk.

A systems approach is justified by the need to understand the structure, operation, and evolution of a farming system, in order to assess the impact of new technology. It is also necessary to understand the links between technical and socioeconomic factors, on one hand, and the evolution of the production environment and the farm adaptation process, on the other. Particular attention must be paid to farmers' practices as part of the decision-making system (Milleville 1987; Landais and Deffontaine 1991).

Regarding use of the local approach, there were two main justifications. First, relationships between the environment and farmers' practices are best observed at that scale. Second, the local approach allows consideration of the interaction between social and geographical proximity (OCS 1986). Geographical proximity is considered here as favorable for the dissemination of specific technological externalities such as labor or innovation (Requiers-Desjardins 1988).

Mathematical programming is particularly well suited to simulating strategic choices made according to this model, as it allows optimization of the farmers' objective function, subject to their constraints (the endogenous factors managed by technical actions and which interact with exogenous factors). The adaptive evolution of the farm can be described using a recursive model in which the results of one production cycle influence the initial conditions of the next (Fig. 1). Mathematical programming also allows easy incorporation of data from several sources (biophysical models, expert opinion, survey data), and is especially indicated when big changes are taking place, as is occurring with policy in Mexico and Brazil. Finally, risk can be accounted for, as described below.

Methodological steps:

1. Characterization of natural resource (agroecologic zoning) and farming systems (typology) diversity.
2. Characterization of the farming system(s) and relationships between biophysical and socioeconomic factors. Twenty to thirty farms were chosen, selecting from each agroecological zone and, within zones, from each type of farming system. The selected farms were monitored for three years.
3. Development of biophysical and socioeconomic models; calibration and validation of the models using the monitored farms.
4. Integration of both models.
5. Use of the models to run simulations of the proposed technologies under several scenarios of exogenous variables (climate and prices) to assess the impacts of the new practices.
6. Sharing the results with farmers and policy makers.

Modelling methodology

Accounting for risk

Several techniques have been developped to account for risk in mathematical programming (Boisvert and McCarl 1990; Hardaker *et al.* 1991). The model should integrate the three decision making stages in which risk is considered by farmers:

1. *Ex-ante*, before the real conditions are known, risk management strategies are implemented at the plot and farm level through diversification of crops, cultivars, activities, livestock, land types, etc (Matlon 1990).
2. During the production process, farmers adapt to the climate and economic conditions.
3. *Ex post*, risk coping stategies, such as mutual insurance, consumption adjustment, credit, etc., help the household survive.

Risk management and risk coping strategies are often studied separately. However, at the farm level these are interrelated problems. For example, if a farmer has various ways for coping with a bad year, risk management strategies are less necessary. Therefore, for a proper representation of farmers' decisions, both aspects should be included in the model. Risk management strategies are studied using "risk programming," in which the objective function includes an attitude toward risk. One of the most popular approaches is the "target MOTAD" (Tauer 1983), which considers that the farmer's first concern is to save his enterprise, whatever the scenario encountered. Given this constraint, the farmer tries to optimize his expected revenue. To simulate changes in farmers' decisions during production, stochastic programming is necessary. This allows the introduction of uncertainties, not only in the objective function but also in the input and output coefficients and in the constraints levels.

Assessing farmers' constraints

Farm monitoring included monthly observations for an entire year of cash, labour, land and cattle management. Most productive functions of the model, which link productive resources to an economic result according to a set of management techniques, are directly inferred from the data of this farm survey. Each modelled farm is divided into different agro-ecological zones, each associated with a land constraint. The year is divided in several seasons to account for competition for labour or cash at certain periods.

Using a crop model

In the case of maize, the productive function could not be deduced from the farm survey data. The variability of yield for any given combination of a set of techniques and a type of environment was very high, due to numerous interactions between soil, plant, climate, and techniques. As farm income is highly dependent on maize yields in both regions, and as this is the main way farms are exposed to climatic risk, a crop model appeared necessary to provide a time distribution of yield accounting for these interactions. Additionally, an adequate crop model could help to analyse the long-term effects of the management techniques on the environment and thus on farm sustainability. It is worth noting that the technical package adopted by farmers in Silvânia was suspected to increase soil erosion, while the no-tillage sowing in straw mulch proposed in San Gabriel had been found clearly to reduce it, in experimental plots.

"Ready-to-use" crop models, such as EPIC, CERES or CROPSYS, are available and widely used by economists to inform farm models. However, as they use not only theory-based equations but include empirical relations, none is universal (Passioura 1996; Sinclair and Seligman 1996). In some cases their limits may appear clearly to users due to obvious incompatibility between the data required and the situation studied. But more frequently, the suitability of a crop model can only be assessed through careful validation requiring, among other things, skills in biophysical agronomy. Deybe (1989), Barbier (1994) and Velloso (1990) are among the few studies in which agroeconomists took care to test EPIC before using it for a tropical context. They showed a lack of accuracy in various of the model's components. Despite this, farm models using crop models have been applied in numerous studies involving tropical regions, with no attempt to link the reliability of the farm model to that of the crop model. Moreover, the carefully phrased remarks which generally follow the crop model validation, if present, and come before its application, are often distant in the reader's mind by the "conclusions" section of the text, lending those judgements undue credibility and impact. To avoid this in our study, biophysical agronomists were in charge of providing simulated yield distributions to economists' farm models. The STICS generic crop model (Brisson and Mary 1997) was chosen as a starting point because:

- Its water balance module was very similar to the one already calibrated and validated for both sites.
- It was a recent model designed to correct some of the most commonly-cited shortcomings of older generic models, such as CERES and EPIC.

Preliminary results

We are still developing the economical and biophysical models, but present some preliminary results here.

Biophysical model

Using data from experiments, the model was validated for restricted cases where the only constraints were solar radiation, temperature and water. A diagnosis of the factors involved in yield variability in farmers' fields was performed using the methodology of Leterme *et al.* (1994). The results show that numerous model components would have to be added to STICS and to any other model to simulate realistic yield distributions for our study sites. Factors such as weed infestation, soil water saturation limiting root extraction activity, heterogenous and low plant populations, high soil acidity, and runoff have a relatively strong effect on yield, whereas they are among the weakest model components in the most popular models, when present. Modelling their effects mechanistically, however, would have required long-term experiments. As an alternative strategy, we deduced empirical relationships from our dataset between these factors and yield components that remained unexplained by STICS.

Economic model

In Brazil, initial simulation results are consistent with empirical observations; i.e. specialization and intensification with increasing use of chemical inputs, justified by the relative evolution of input and output prices, in favor of milk production. The optimal solution, however, is highly dependent on certain variables, including maize yields, which justify careful crop modelling to understand why some farms specialized and others did not.

In Mexico, the availability of cash at the beginning of the agricultural year strongly influenced input levels, a result amply confirmed by observations, as farmers use numerous forms of credit, most with very high interest rates, at the start of the rainy season.

Coupled model

Our first attempt to use data from the crop model in the farm model provided methodological insights. The two models were interfaced through the production function. Within the scope of the general methodology for risk coping, it appeared that price and yield variation over time could be considered in three different ways, each one implying a specific type of model interfacing: 1) a reduced set of "states of nature" is defined to represent farmer predictions for prices and yields for each combination of management techniques, activity, and soil; typically, a "bad year," an "average year," and a "good year" are considered, each one associated with its probability of occurrence; 2) time series of prices and simulated yields define the set of states of nature, representing the scientific knowledge of price and yield variation; 3) combining these two approaches, the economic model calculates farmers' technical choices based on farmers' predictions of states of nature, while time series of prices and yields are used to evaluate, year after year, the farm income resulting from such choices, taking into account the transfer of resources from one year to the next.

In all cases, the biophysical model was used to generate the states of nature for yields, considering a set of management techniques and land constraints. This set was defined as a compromise between economists and biophysicians concerning the precision of farm diversity descriptions. In the first case, it was impossible to reduce the 15 simulated years to a typical set of "good," "bad," or "average" years. This was due to strong interactions between management, soil, and climate factors, as a given year could appear favourable for some sets of techniques while very unfavourable for others. As a result, it would be useful to obtain a representation of yield variability from farmers themselves, through a survey, and compare it with model results, directly and in terms of influence on adoption behavior. The third type of modelling would provide information on the how efficient farmers' predictions are in dealing with real variability.

Additionally, and as a result of the multi-disciplinary work, the crop modellers involved in this study found that development of the crop model could be driven by the farm model. The fact that a given phenomenon has a high weight in yield variability does not necessarily imply that the effect of this phenomenon should be accurately simulated, in the perspective of providing data to a farm model. What *does* matter is if the confidence interval of the simulated yields is included or not in the sensitivity interval of the farm model for crop production activities. This sensitivity interval gives the limits of yield associated with a type of management technique and soil, between which the choice of activities, as optimized by the farm model, would not vary. This means that accuracy requirements for the crop model are given by the farm model: the weight of a factor in yield variability has to be analysed relative to farm model sensitivity. Thus, incorporation of new components in the biophysical model should be driven by both the causes of yield variability and the sensitivity of the farm model to inaccuracies in the crop model. Considering this, we think that close multidisciplinary work in farm modelling would help avoid two major risks in this type of study: 1) the inadequate use of biophysical models by economists; i.e., failing to consider confidence intervals of simulated yields; and 2) useless and time-consuming biophysical complexity in the crop model, due not considering sensitivity coefficients of farmers' technical choices, as simulated by the socioeconomic model.

Conclusion

To study the evolution of small-scale farms facing macro-economic changes, a modelling approach is needed, as numerous interactions between endogenous and exogenous factors are involved. The models should account for farm diversity to explain why farming systems and farmers show contrasting reponses to similar macro-economic changes. The use of crop models to provide data for mathematical programming of farm models seems a powerful way to account for farmers' strategies toward climatic risk and/or ecological sustainability. To avoid inadequate use of these biophysical models, however, close interdisciplinary work is needed between economists and agronomists.

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Tables and Figures:

Table I : Effect of the innovative packages on average yield and its variability

		Inter-annual average yield (T/ha)		**Variation Coefficient (%) (Std.Dev./Mean)**	
		Traditional package	Innovative package	Traditional package	Innovative package
Mexico	Humid Zone	5.0	5.2	30	23
	Dry Zone	2.0	3.3	49	33
Brazil		3.2	6.1	9	26

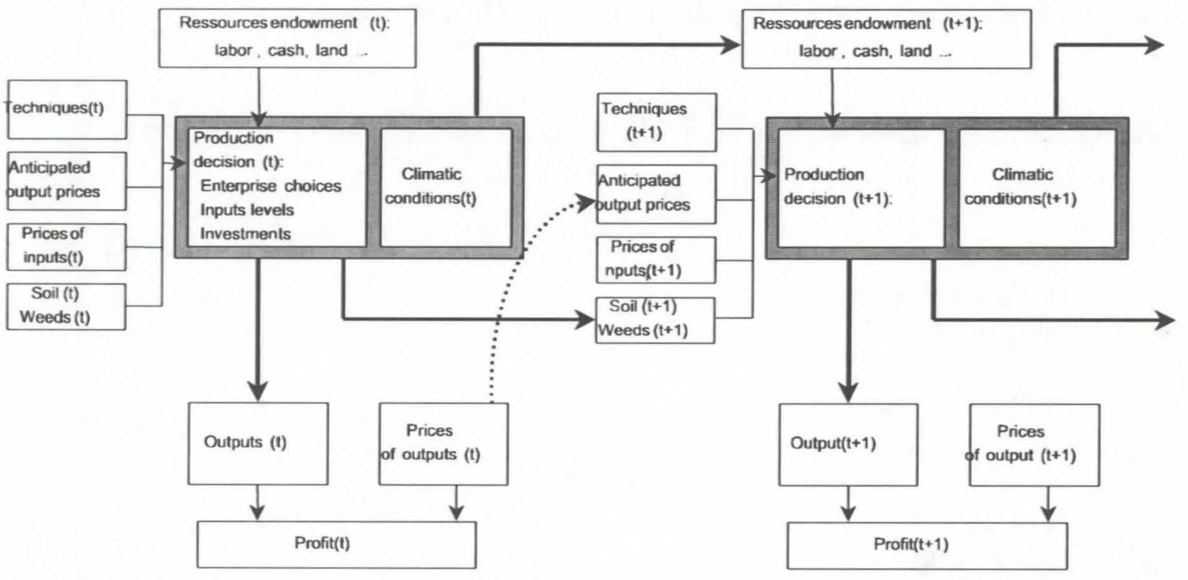

Figure 1. Inter-temporal considerations within the decision framework.